DOCUMENT RESUME

ED 431 616 SE 062 596

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TITLE Learning in Science: How Do Deep and Surface Approaches Differ?
PUB DATE 1999-04-00
NOTE 20p.; Paper presented at the Annual Meeting of the American Educational Research Association (Montreal, Canada, April 19-23, 1999).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE EDRS Price MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Chemistry; *Cognitive Style; Epistemology; Foreign Countries; Grade 8; Junior High Schools; Learning Processes; Learning Strategies; *Science Education; *Science Laboratories

ABSTRACT

The purpose of this study was to compare in greater depth the qualitative differences between what previous researchers have called a deep versus surface approach to learning science. Six grade 8 students judged as typical using a deep or surface approach were videotaped or audiotaped during class group laboratory activities in a chemistry unit. They were also interviewed individually before and after instruction about related science concepts. On analysis of students' discourse and actions during the activities and their interview responses, several differences in learning approaches seemed apparent. These differences fell into five emergent categories: (1) generative thinking; (2) nature of explanations; (3) asking questions; (4) metacognitive activities; and (5) approach to tasks. When students used a deep approach, they ventured into their ideas more spontaneously; gave more elaborate explanations which described mechanisms and cause-effect relationships; asked questions which focused on explanations and causes, predictions, or resolving discrepancies in knowledge; and engaged in "on-line theorizing." Students using a surface approach gave explanations that were reformulations of the questions, a "black box" variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible. Their questions also referred to more basic factual or procedural information. The findings also suggest that to encourage a deep learning approach, teachers can provide prompts and contextualized scaffolding and explicitly encourage students to ask questions, predict, and explain during activities. (Contains 19 references.) (Author/NB)

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Paper presented at the Annual Meeting of the American Educational Research Association, 19-2 April, 1999, Montreal, Canada

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Abstract: The purpose of this study was to compare in greater depth, the qualitative differences between what previous researchers have called a deep versus surface approach to learning science. Six grade 8 students judged as typically using a deep or surface approach were videotaped or audiotaped during class group laboratory activities in a chemistry unit. They were also interviewed individually before and after instruction about related science concepts. On analysis of the students' discourse and actions during the activities and their interview responses, several differences in learning approaches seemed apparent. These differences fell into five emergent categories: generative thinking, nature of explanations, asking questions, metacognitive activity, and approach to tasks. When students used a deep approach, they ventured their ideas more spontaneously, gave more elaborate explanations which described mechanisms and cause-effect relationships, asked questions which focused on explanations and causes, predictions, or resolving discrepancies in knowledge, and engaged in "on-line theorizing." Students using a surface approach gave explanations that were reformulations of the questions, a "black box" variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible. Their questions also referred to more basic factual or procedural information. The findings also suggest that to encourage a deep learning approach, teachers can provide prompts and contextualized scaffolding and explicitly encourage students to ask questions, predict and explain during activities.

Students adopt different learning approaches as a result of both individual characteristics (e.g., ability, locus of control, motivation) and situational factors (e.g. nature of task, learning context, perceptions of institutional requirements, background knowledge). This could be a deep approach characterized by meaningful learning or a surface approach characterized by rote learning (Biggs, 1987; Entwistle & Ramsden, 1983). The learner adopting a deep approach focuses on understanding the content of the learning material, attempts to relate parts to each other, new ideas to previous knowledge, and concepts to everyday experiences. On the other hand, the learner who uses a surface approach tends to memorize discrete facts, and views a particular task in isolation from other tasks and from real life as a whole. Research in science education also suggests that a student's learning approach is a factor influencing his or her learning outcome. The study by Cavallo and Schafer (1994) on grade 10 students' understanding of genetics topics showed that the more meaningful the students' learning orientation, the more meaningful the understanding (as measured by the inter-relatedness and complexity of their knowledge exhibited) they tended to attain. Studies by Hegarty-Hazel and Prosser (1991a, 1991b) showed that for both student learning in electricity and photosynthesis, deeper and more meaningful strategies were associated with better developed propositional knowledge and more surface strategies with less developed propositional knowledge. BouJaoude (1992) found in a study of high school students, that the relatively meaningful learners

performed significantly better than the rote learners on a misunderstandings post-test in chemistry and for the most part, developed more coherent understanding of the underlying concepts.

In light of the above findings, it is thus of interest to determine how students with different learning approaches construct their understanding of scientific concepts. Much of the early research on differences in students' learning have typically compared the learning outcomes of successful and unsuccessful learners. Many of these studies used a behaviorial approach to determine the effects of an independent measure on a dependent measure to find out how much was learned. The focus of such studies was on the quantitative outcome of learning. Although some studies (e.g., Baird & White, 1982) have provided some information about qualitative differences in learning in terms of application of cognitive strategies, few studies have been made that have a sufficiently descriptive approach to offer teachers new pedagogies to help improve student learning. Thus, examining how students differ in the way they learn may shed light on the processes of knowledge acquisition that lead to different learning outcomes.

Most of the earlier research on students' learning approaches was on reading from text (Marton & Saljo, 1976) and domains other than science. Although a few more recent studies have been carried out on the learning of science, these have focused on the relationship between students' learning approaches and their science performance (e.g. BouJaoude, 1992; Cavallo & Schafer, 1994; Dall'Alba, 1986; Hegarty-Hazel & Prosser, 1991a, 1991b). Less research has been done on how students' learning approaches and learning strategies relate to the development of their conceptual knowledge, and how the use of these strategies figures into educational discourse, particularly in a naturalistic setting. Also, little is known about the strategies that enhance deep level learning in science. What is needed is a better understanding of the cognitive processes underlying knowledge restructuring that might lead to conceptual change, how cognitive processes interact, and the ways in which they serve to enhance and propel knowledge acquisition and conceptual change processes. Thus, the primary purpose of this study was to compare and provide descriptive information about differences in the learning approaches that students use. This problem and its related findings are important because there exists no principled and detailed account of the characteristics associated with learning approaches specifically in the context of science learning. This information would shed light on understanding individual differences, provide further insight into what is meant by a deep and surface approach in the specific context of science learning, and extend our understanding of students' learning approaches beyond earlier conceptualizations which were more general in nature.

Method

A grade 8 science class from a school in a midwestern university town in the US was observed throughout the period of instruction on a chemistry unit which lasted nine weeks. Six target students representing learners using a deep or surface approach to learning were selected for more in-depth study. They were identified by the Learning Approach Questionnaire based on a modification of Entwistle & Ramsden's (1983) instrument and their teacher's evaluation of their learning approaches in science. The questionnaire was a 31-item Likert instrument which

measured students' tendency to learn meaningfully using a deep approach or by rote using a surface approach. The Cronbach alpha reliability coefficients of internal consistency for the meaning orientation and reproducing orientation scales were .86 and .65 respectively. Test-retest reliabilities over a 9-day period were .86 and .80 respectively for these two scales. Other selection criteria included: good attendance, being verbally expressive, being on-task, at least average success in science, and ability to work well with each other.

The students worked in two groups of three during their class activities. The group assignment was done by the teacher who in the past had experienced greater success with same-sex groups. The boys' group consisted of Rick, Quin, and Carl while the girls' group comprised Mary, Bess, and Dale. Rick and Mary were identified independently by both the Learning Approach Questionnaire and the teacher, as meaningful learners who typically used a predominantly deep learning approach, Carl and Dale as rote learners who typically used a more surface approach, while Quin and Bess used an approach that lay somewhere between a deep and surface approach. Rick and Mary were "A" students, Quin and Bess were "B" students, and Carl and Dale were "C" students. The boys were audiotaped and the girls were videotaped during hands-on activities during their regular science classes and were encouraged to think aloud and to verbalize their thoughts. Field notes which focused on classroom discourse and science activities were taken. The topics covered in this chemistry unit included the nature of matter (elements, mixtures, compounds, atoms and molecules), states of matter and changes of state, physical and chemical changes, acids and bases. Laboratory activities included the separation of a salt-sand mixture, plotting the temperature graphs of water and salt water, and paper chromatography using different colored pen inks. The target students were also interviewed individually both before and after instruction of the chemistry unit to find out more about their understanding of the science concepts in this unit. During the post-instructional interviews, stimulated recall was used to obtain further information about what the students were thinking of during the laboratory activities. This provided information about silent thoughts which were not always verbalized and captured on tape.

Data from multiple sources (field notes, transcripts of classroom discourse from the audiotapes and videotapes, audiotaped interviews with the students, and students' written work) were analyzed in relation to each other; this served to triangulate the data and to help enhance the credibility of the findings and assertions made (Lincoln & Guba, 1985). The target students' taped interviews and discourse during class activities were transcribed verbatim and analyzed to determine the nature of their reasoning, argumentation, and sense-making during their engagement in problem-solving activites and in the development of their conceptual knowledge. Transcribed discourse from the videotapes was also supplemented with descriptive notes obtained by viewing the videotapes; this pertained to the students' actions, behaviors and expressions. Of particular interest were the differences between learners using a deep and surface approach to learning. The transcripts were studied closely to search for any salient and recurring themes pertaining to these differences.

Results

From an analysis of the data, five categories emerged as meaningful perspectives that would illuminate the differences between deep and surface approaches to learning. These were (a) generative thinking, (b) nature of explanations, (c) asking questions, (d) metacognitive activity, and (e) approach to tasks. While the deep strategies were used more consistently by the deep approach learners than the surface approach learners and were characteristic of their predominant learning mode, there were occasional instances when the students classified as surface approach learners used deep strategies and when those classified as deep approach learners used surface strategies. In the discourse segments, the following transcript conventions are used: [...] pause (3 s or shorter) [.....] long pause (more than 3 s)

Generative Thinking

Generative thinking refers to the students' ability to generate an idea when they did not have an immediate ready-made solution to a problem, particularly so when the problem was not familiar and the students could not rely on simple recall of facts or something learned by rote. It embodies ideas of creativity, lateral thinking, and fluency in the generation of ideas. Four main levels of generative thinking emerged, corresponding to differing degrees of generativity. In level 1, the students remained stuck, saying "I don't know" and did not proceed with thinking further. In level 2, the students gave an "evasive" response that did not directly answer the question but was related to it. In levels 3 and 4, the students attempted to think hard and give an answer which might be correct or incorrect. While the answers at the third level were short and lacking in details, answers at the fourth level were more elaborate and often more richly illustrated with specific examples and references to real life experiences. Levels 1, 2, and 3 would be characteristic of a surface approach to learning, while level 4 would be typical of a deep approach.

The following example illustrates the differences in generative thinking. During the post-instructional interview, the students were asked questions pertaining to the class activity on paper chromatography of pen inks. As they had performed the activity in a rather procedural manner and seemed not to have thought about why it might be useful or important to calculate the retention factor, R_f, they were asked what they thought chromatography was used for and what was the purpose and significance of calculating the R_f for each color spot. In class, the teacher had only introduced the R_f as simply a formula, $R_f = D_C / D_S$, the distance the color moved (D_C) divided by the distance the solvent moved (D_S).

Carl had blindly followed the instructions to calculate the R_f and said "I didn't think. Just did it." He could not think of the purpose and significance of finding the R_f and remained stuck, saying "I don't know" repeatedly when coaxed for a possible answer. This would be an example of level 1 of generative thinking. Bess had also just followed the procedures blindly and was unable to come up with an idea of what the R_f might represent. When asked what was the purpose and significance of finding the R_f, she gave a response "so that we could understand it a little bit more" that did not specifically answer the question (level 2). Subsequently, upon further coaxing,

she was still unable to generate an interpretation of the R_f, remaining stuck and saying "I don't know" (level 1). Finally, when asked what chromatography was used for, she responded with "to match something" without giving any specific referents or elaborating any further (level 3).

Now compare the answers given by Rick and Mary. Although their ideas of the R_f were not in accordance with the scientific view, they were able to generate on the spot answers that seemed plausible and quite complete in themselves compared to the other students, despite not having any extra content knowledge about the R_f. Rick thought of the R_f as being associated with the relative proportions of the component colors of the ink and gave a specific hypothetical example to illustrate his ideas. Also, when asked about the applications of chromatography, he gave an example about mixing different shades of colors in artist's paints that was slightly different from the activity done in class, but consistent with his idea of the R_f as a measure of the relative proportions of the component colors:

> How to mix different colors. Like if you want artist's paints. Maybe he doesn't want brown but he wants lightish brown. So he needs to find out what the standard brown is made up of [...] so maybe he can add more of one substance and less of the other and form different colors of brown.

Rick's response to the question would be illustrative of level 4 of generative thinking activity.

When Mary was asked to suggest a possible use of the R_f value, she came up with the idea of the R_f as an index of the purity of a substance, saying, "that must mean that it's like a pure color ... it doesn't have any colors that mix up to make with it ... so I know this isn't going to kill me if I ingest it." As for applications of chromatography, she also gave examples that were not simply exact reproductions of the "crime lab chemistry" class activity regarding a ransom note. Rather, her ideas were extensions of the activity and she mentioned the use of the R_f in identifying samples of food dyes, blood, and clothing dyes in forensic science. Here again, there was generative thinking at level 4. Rick and Mary were not inclined to say "I don't know" when they were confronted with something that they did not have a ready answer for. Instead, they would attempt to think and give a plausible answer.

When students used a deep approach, they tended to venture their ideas more spontaneously. Their responses were more sustained, interconnected, elaborate, and precise with specific referents. The students usually resorted to daily life experiences, past episodes, examples, and self-generated analogies as tools to keep the thinking going. This indicates a greater degree of cognitive processing which helped them to maintain their thinking continuously as a "chain reaction" compared to the "piecemeal thinking in spurts" shown by the other students when they were stuck for an answer. On the other hand, students using a surface approach tended to give up thinking more easily, or gave a vague response that did not answer the question directly, or that was brief and unelaborated. Their thinking was more piecemeal and the students moved from one idea to another without a sense of directional link between the isolated ideas. They seemed to be more dependent on recall of factual knowledge. A point worthy of note about the students' generative thinking was that their deep thinking

processes sometimes remained latent unless stimulated by external sources or intervention. For example, even the deep approach learners, Rick and Mary, did not think about the meaning of the R_f in the chromatography activity until they were probed during the interview. This suggests that deep generative thinking may not always be spontaneous but is manifested through another person's scaffolding, prompting, or stimulation, and requires the interaction of situational factors and a pre-existing cognitive tendency.

Nature of Explanations

There were four main types of explanations, reflecting different levels of depth and sophistication. The explanations associated with a surface learning approach tended to be reformulations of the question (level 1), of a "black box" variety (level 2) which did not refer to a causal mechanism, or macroscopic (level 3) which referred only to what was visible. Black box explanations included mere observations or descriptions of what happened instead of telling why or how an event occurred, rote explanations in which the student gave textbook-like answers that sounded scientific but did not relate meaningfully to the situation, global explanations which lacked specific referents, "cyclic" explanations in which the student switched back and forth between two ideas without advancing, and anthropomorphic explanations. These explanations were also sometimes vague with non-specific referents, and less elaborate. They were typically given only when solicited and the student required more probing to generate a more complete explanation. In contrast, a learner using a deep approach tended to give "microscopic" explanations (level 4) which described non-observable theoretical entities and cause-effect relationships. This type of explanation was like a model or mini-theory which served as a link between the macro and micro levels. To generate such an explanation, the student often used mental imagery, analogies, real-life experiences, or hypothetical examples to articulate his or her ideas. The explanations were also given more spontaneously by the student.

The boiling point activity will be used to illustrate these different types of explanations. After plotting the temperature graph for ice water as it was heated to boiling point in the absence and presence of salt, the students were asked why the temperature stayed constant at 100 °C when plain water boiled, and about the effects of adding salt to the water. Rick had initially thought that the temperature of plain boiling water would increase beyond 100 °C. However, during the activity he sought to address this conceptual conflict by self-generating an explanation to account for the anomalous data, saying "I think it's getting hotter but because the water is evaporating, the temperature doesn't go up." During the post-instructional interview, Rick elaborated on his new idea that heat was leaving with the evaporated water, "it could have been heating up but because the water was leaving, it wasn't trapping as much heat. So it kind of stayed at the same level .... I guess it [heat] went away with the evaporation of the water. It was like leaving with it." Rick had formed an idea of the heat of vaporization although this concept was not formally introduced in class. What was it that made him offer an explanation so spontaneously during the activity which he later refined and elaborated on during the interview? Perhaps it was his inclination to anticipate outcomes that made him alert to discrepant data.

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Also, unlike the other four students (Carl, Quin, Bess, and Dale) who could not think of any reason for why salt lowered the melting point of ice and raised the boiling point of water, Rick had ready explanations for these observed phenomena. Before doing the activity, he thought the melting point of salted ice would be lower "since it [salted ice water] had more particles, it kind of trapped more cold than just the plain water." He also thought the boiling point of salted water would be higher because "there were more particles in it and it would attract more heat than just plain water. It would kind of trap the heat while the water just lets it run through." After carrying out the experiment, Rick found that the boiling point of salt water was 102 °C. He explained:

> Salt in it ... makes the water thicker. And it kind of took more heat to melt the water that had salt in it .... it [salt] kind of fills up a lot of empty spaces between the [water] molecules. And so the heat couldn't pass through it as fast as it did through the plain water. So it had to add more heat to break through the salt particles and heat up the water.

Rick gave an explanation at the molecular level beyond what was perceptually obvious. None of the other students gave an explanation in molecular terms. It is possible that his observation that salt "makes the water thicker" could have triggered him to think of the salt molecules filling up the empty spaces between the water molecules. Another noteworthy point about Rick's explanations is that although they were not completely normative, they were coherent in themselves and were attempts to come up with a model or mini-theory that would explain the mechanism of how things worked in the physical world beyond what was visible. He referred to unobservable theoretical entities such as particles and molecules, and attempted to link these at the micro level with his observation at the macro level, describing a cause-effect relationship. His "microscopic" explanation would be an example of level 4.

Mary also predicted that salt would raise the boiling point of water. She thought about how she had used salt on the driveway to melt snow in winter, and reasoned that the temperature of "salt water would rise a little bit higher than regular water because it would conduct more heat due to the salt." She also thought that salt would "create more heat" to speed up the heating of water. Referring to the chemicals in salt and anti-freeze, she thought that it had "something to do with the chloride in it that makes the thing heat hotter .... like anti-freeze for your car has some kind of chloride in it. And that's what keeps the pipes in your car from freezing." Regarding the effect of salt on the boiling point of water, Mary thought of "boiling baby bottles," saying "salt water sterilizes things .... it'll make the water hotter so that it will kill more bacteria and stuff that are on the baby bottles. I learned that from a friend who I baby-sit for." Like Rick, it was also natural for Mary to predict and theorize about how and why things happened the way they did. The striking thing about the way she generated her explanations was that she often related the phenomenon being considered to her experiences in daily life (e.g., use of salt in melting snow, as an anti-freeze in cars, and in sterilizing baby bottles) and attempted to make connections between them. She also seemed to be trying to postulate a mechanism and cause-effect relationship; her explanation would also be an example of level 4.

When asked why she thought the temperature remained constant when water boiled, Dale did not give a causal explanation but described her graph instead, merely stating her observation. Upon further probing she replied, "because it can't get any hotter." Her answer was more a reformulation of the question in different words (level 1). Before doing the activity, Dale thought that the salt would make the water heat up "faster" although she could not give a specific reason for this. Unlike Rick's answers which referred to a mechanism that might account for the observation, Dale's response "because ... just adding something might help it" was vague in that it did not specify any cause-effect relationship and there were no specific referents. Her ideas were of the "black box" variety and had little explanatory power (level 2). Bess' attempts to explain the effects of salt on the boiling of water resulted in a cyclic explanation where her responses kept returning to the former idea without advancing in any way. When she was asked how salt water affected the temperature curve, she said "it gets hotter faster." Then in response to why that might be so, she replied "because it has got salt in it." When she was then again asked how salt might affect it, she returned to her former idea that "it just makes it get hotter." Thus, her responses were "cyclic" in that she kept going back and forth between these two ideas. Such a "cyclic explanation" is also of the "black box" variety because it does not offer a mechanism nor explain how the observed effect might occur. Quin's explanations for the temperature remaining constant during the melting of ice was anthropomorphic in nature, in that he attributed human qualities to the ice. Referring to the bottom plateau of the graph where ice was melting, he said, "it was like it couldn't make up its mind. It was battling like the heat and the cold."

In sum, level 4 explanations that were associated with a deep learning approach were more coherent, focused on the mechanism of how things worked in the physical world, and tended to be more like mini-theories or models which attempted to account for what was not perceptually obvious. In contrast, explanations at levels 1 to 3 focused on the gross and macroscopic aspects of students' observations or were restatements of the question. Sometimes, they also had a "black box" quality to them in that they were not really explanations as they did not describe any causal links nor a mechanism for how things happened.

Asking Questions

Questions associated with a surface approach referred to more basic, factual (requiring only recall of information), or procedural information. Factual questions were often closed questions with a single, unambiguous answer. They typically related to information in the textbook, or some simple observation about an event. Examples would be "what does the dictionary say about salt?" and "what color is that? Blue?" Procedural questions were those which sought clarification about a given procedure or asked how a task was to be carried out, particularly where step-by-step instructions were given. Examples would be "did she [teacher] say to put it in a pan?" and "could we pour this out now?"

Questions associated with a deep approach to learning tended to be "wonderment" or thinking questions which reflected the students' curiosity, puzzlement, skepticism, or speculation. They focused on explanations and causes, predictions, or on resolving discrepancies in knowledge. They were pitched at a conceptually higher level, required an application or extension of taught ideas, and

apparently sprung from a deep interest of the students or arose from an effort to make sense of the world. They were asked when students tried to relate new and existing knowledge, integrate complex and divergent information from multiple sources, or build internal associations among different aspects of the new knowledge in their efforts to understand. Unlike basic factual and procedural questions which were typically either ignored or simply responded to with a simple short answer, wonderment questions served to direct further inquiry, tended to elicit responses that were of a more conceptual nature, and had a greater potential contribution for an advancement in conceptual understanding. Students who used a deeper approach to learning tended to ask wonderment questions more spontaneously perhaps because asking such questions is, to a large extent, related to the inclination to self-generate explanations and construct theories.

Wonderment included (a) comprehension questions which typically sought an explanation of something not understood (e.g., "why do some pen ink run faster than others?"), (b) prediction questions which were of the "what would happen if ..." variety involving some speculation or hypothesis-verification (e.g., "if you put more than one color, would it separate into just more colors?"), (c) anomaly detection questions in which the student expressed skepticism or detected some discrepant information and sought to address this anomalous data (e.g., "so it's staying at 100 ^{o}C?"), (d) application questions in which the student wondered of what use was the information that he or she was dealing with (e.g., "what is the R_f used for?"), and (e) planning or strategy questions where the student was temporarily stuck and wondered how best to proceed next when no prior procedure had been given (e.g., "how are we going to recover the salt from the solution?"). This list of categories of wonderment questions is not exhaustive, but includes most of the common questions that students usually asked. A point worthy of note is that wonderment questions were not often asked spontaneously by the students. However, when the students were encouraged to ask questions and think more deeply about what they were doing, such questions were generated.

Metacognitive Activity

This refers to the students' use of comprehension-monitoring and evaluative strategies that indicate they were reflecting on the learning process and their strategy of thinking, and were aware of the status of their comprehension. It includes two essential features: knowledge about cognitive states and processes, and regulatory (i.e., control or executive) aspects (Baird, Fensham, Gunstone, & White, 1991; Brown, 1978). The students who used a deep approach to learning displayed more cognitive self-appraisal and regulatory control of the learning process through ongoing reflective thinking, whereas those using a surface approach engaged in less self-monitoring and self-assessment. When students used a deep approach, they (a) constantly self-evaluated their ideas by making statements that expressed their understanding (e.g., "I've figured out what I wanted to say!"), that recognized a comprehension failure or impasse (e.g., "no, I don't get it"), and that expressed value judgments (e.g., "I know I'm just rambling on", "oh no, I didn't draw that right, I'm getting confused"), (b) made self-questioning statements when they encountered something that confused them or when they realized that there was a block in their understanding (e.g., "oh no, what am I going to do?"), (c) detected their errors and spontaneously self-corrected them, (d) noted and attended to anomalous data and

counter-intuitive events, (e) considered a range of possible answers and attempted to understand alternative ideas, and (f) considered limitations in their own or others' ideas and critiqued them.

The following example shows how Mary noted errors in her own thinking and spontaneously made changes to them. Unlike the other students who tended to give an answer and stick with it, Mary's thoughts were constantly in flux, thus leading her to reconstruct her ideas and revise her original answers. When discussing her understanding of chemical and physical changes, she initially thought that burning paper to ash and smoke was a physical change since she saw ashes simply as "paper in a new form" and "not chemically changed." Then she thought about baking, saying "you can mix flour and sugar, and baking soda and eggs and combine them all together to make a chemical reaction with the heat that's baking it to make a new thing." She then realized that heat was a factor common to the two events, noticed the inconsistency in her thinking, and reasoned that "if you burn the paper, ... it could be a chemical change because the heat may have changed some of the properties of the paper .... The heat makes like a char on the paper ". This finally led her to conclude that burning paper involved a chemical change.

The difference between learners using a deep approach and those using a surface approach was not so much due to the amount of content knowledge they possessed as to the way they went about tackling a problem or new information. For example, Mary, as a learner who often used a deep approach, displayed more planning, control, and both reflection-in-action as well as reflection-on-action. When faced with a problem, she would typically try to recall her past experiences and think of all things she knew that were associated with the problem at hand. For example, she would think of similar tasks which matched the new task requirements, and ask herself questions of the type "have I come across this before?" and "what do I know about this?" And while executing a task, she would constantly reflect to assess the extent to which her implemented ideas were working, revise or modify them when necessary, make constant on-line adjustments, and use alternative strategies if needed. She stopped periodically to assess the progress she was making to check if what she was thinking or saying made sense, and was alert to discrepancies in her thinking. She also used self-questioning as a source of feedback to correct her misunderstandings or redirect her use of learning strategies where necessary. By being strategic, self-regulated, and reflective, she was more aware of when she made errors and was better able to spontaneously identify the loci of her misunderstandings. This, in turn, initiated use of further strategies which enabled her to tackle the problem at hand in an alternative way.

In contrast, when the students used a surface approach, they rarely reflected on their own performance and seldom critically evaluated the new information, compared it with their prior knowledge, or reflected on the efficacy of the procedures used to process the information. They hardly made self-evaluation statements or asked themselves questions such as "why am I doing what am I doing?", "what does this mean?" (e.g., when the students did not question the meaning of the R_f), "why does this happen?", and "does this seem correct?". In this mode of learning, the students did not use an active, interrogative approach. Instead, they followed the given procedures blindly and relied more on memorized facts. Thus, the difference

between a learner using a deep approach and a surface approach was more of a qualitative difference in the strategies that they used.

Approach to Tasks

One characteristic of a deep learning approach was that the student was more persistent in following up on an idea with some sustained interest before moving to another one, while one using a more surface approach might give up an idea as soon as it did not work. When using a deep approach, the student would also attempt to generate ideas on his or her own whereas one using a surface approach would be more reliant on external resources such as other peers or the teacher for ideas. The student using a deep approach engaged in "on-line theorizing" where he or she spontaneously generated explanations for cause-effect relationships and mini-theories to account for observations of phenomena while carrying out tasks and also tended to think ahead and predict outcomes when performing an activity. He or she was also more capable of attending to multiple foci, and could focus on several aspects of a phenomenon at the same time, while a surface approach learner had a more limited or single focus. When a student used a deep approach, he or she did not ignore information that was incomprehensible but rather ruminated over this puzzlement instead of letting it slip by. Such a student also showed a more sophisticated level of observation and was better able to discriminate finely between differences in not only what was visible and obvious, but also inferred patterns and trends. In contrast, a learner using a surface approach noticed mainly gross, macroscopic features. Finally, a deep approach learner was also more likely to engage in talk at the conceptual, analytical, and metaconceptual levels, beyond the procedural and observational levels that the surface approach learner typically engaged in.

To illustrate the above-mentioned differences, consider the girls' group. Mary, who used a predominantly deep learning approach had an inquiring mind, was curious about things, and displayed a predominantly "exploration" mode of engagement toward phenomena (Rath & Brown, 1996) where her primary interest was to find out about the phenomena and study their basic properties. Bess often relied on Mary, other classmates, and the teacher for instructions and sources of ideas, and displayed a "busy bee" orientation towards the activities. She often tried to see what others were doing and how they were making use of the materials and apparatus provided. Her mode of engagement would typically be "procedural" where she followed or imitated others' actions and carried out the given instructions as best as she could. Dale, in contrast, was relatively passive in task engagement, often assuming the role of an onlooker, and spoke little. She would typically sit back and watch Mary and Bess perform the activity first before trying them out herself later, and let her partners perform the more challenging tasks which required more thinking and active engagement. Her mode of engagement typically fluctuated between "procedural" and that of an "onlooker." Selected episodes from two activities will be given to illustrate the behaviors, verbal comments, and thinking processes associated with these approaches to tasks.

Separation of salt-sand mixture. This was a problem-solving activity where the students had to devise a method of separating the salt from the sand. Mary first suggested using a sifter and then looking up a dictionary to find out the chemical composition of sand and salt. Unlike Mary who attempted to generate her own ideas

and dwell more on them. Bess kept visiting other groups to see what they were doing and tried to get ideas from them, giving up one idea as soon as it did not work. Together with Mary and Dale, she tried using a magnet, creating static electricity by using a plastic filter funnel and a plastic spoon, heating the salt-sand mixture dry, and then finally adding water to the mixture followed by draining off the sand residue and evaporating the water from the salt solution over an alcohol flame.
Mary displayed not only a "hands-on" orientation to the activity, but also a "minds-on" approach to the tasks, observing several details. For instance, when the salt solution was boiling, Bess seemed to have only a single focus and was fixated on the presence of salt in the solution, making comments such as "I still see a lot of salt," and "it's like crystallizing." Mary, on the other hand, was better able to notice nuances in her observations, as well as focus on multiple aspects of the phenomena. For instance, she noticed the sizzling effect of adding cold water to the hot, dry mixture, the salt dissolving in the hot water, the salt settling down to the bottom of the pan when more water evaporated, and the salt grains spluttering and sticking to the edges of the pan.

One major difference between Mary and her partners was her engagement in on-line theorizing where she came up with tentative hypotheses, generated self-explanations for cause-effect relationships, and theories to account for her observations of phenomena. In this capacity, she was able to go beyond the kind of thinking displayed by Bess and Dale. For example, when she noticed the water sizzling and the salt gathering around the edges of the pan, she did not simply let these observations slip by without trying to self-explain what caused this to happen. Instead, she theorized about how heating the salt solution could have helped to separate the salt from the water, and how adding cold water catalyzed this separation process when it sizzled.

> [Drawing on paper] These are water [molecules]. When you pour the salt into them, the molecules combine, they stick together.... when you heat the water, the molecules separate. The heat acts as a reactant to separate the molecules.... So that the salt, the sodium chloride molecules gather round at the edges to separate from the water molecules. And the water molecules are left in the middle.... I'll just label this salt water theory.... When we were boiling the water and the salt was gathering around the edges, the water in the pan was hot. And the water that I added was cold. So it made kind of like a spark explosion reaction. Like the molecules didn't agree.... And it made the little sizzling thing. And I think that it increased the process of the salt separating because it made the molecules spin faster.... I was thinking that maybe if the cold water is not agreeing with the hot water, that would speed up the process of the salt separating faster.

Although her mini-theories may seem naïve, they reveal how a deep approach learner might react to ordinary, commonplace situations and perhaps see the extraordinary in the ordinary.

Boiling point activity. The students had to plot the temperature graphs of plain ice water and salted ice water as they were heated in a beaker over a hot-plate

until the water boiled. Mary read the temperature, Bess recorded it, and Dale kept time.

B: 1, 4, 5, 7 [°C] (reading the temperatures recorded for the first 2 min from her data sheet)
D: 30 s.
M: 9 [.....] I'm hypothesizing that the first initial leap in temperature was like the first burst, and then it would gradually go up by 2 [°C] every 30 s.
D: 30 s.
M: 11. See, it's pretty evident that it is going to keep going up by 2, although as the hot plate gets hotter, it might go faster.
B: The ice is about half gone.
D: 30 s.
M: 12.
B: OK, and ice is about half gone [...] more than half.
D: 30 s.
M: 16.
B: And the ice is almost gone now. Almost gone (writing).
M: It's going up a lot faster now. It's already 20 °C and we are not even at the 30 s mark. 21.
D: 30 s.
M: 22.
B: Only like one or two ice.
M: Say ice melted. That's not even ice.
D: 30 s.
M: 29.
B: Ice gone (writing).
M: 100 °C is 212 [°F]. And 212 is boiling point. So once it reaches 100, it should be boiling.
D: 30 s.
M: 36. Look on the bottom and see if it's like going to be small bubbles. Are the small bubbles forming yet?
B: Not yet. No.

At 87 °C, Mary remarked that "this is the third time in a row it had 7 °C as a consecutive number [the temperature difference was 7 °C for the last three times]." When the temperature reached 100 °C, Mary predicted that "it's boiling now, so it will slow down." When the temperature did not rise above 100 °C upon further heating, both Bess and Mary were puzzled by this counter-intuitive observation. This prompted Mary to generate an explanation for her observation, saying "because if it's boiling, it's already at that temperature." Mary told Bess that she thought salt water would get hotter than plain water because "salt is a heat conductor" and that "it wouldn't go above 105 °C.... Because by then the water would have all evaporated."

Again, in this activity, there were obvious differences in the approach to tasks displayed by the three girls. Dale was extremely passive, did not participate "hands-on," and hardly said anything else other than "30 s" when keeping time. In this extreme case, her orientation to the activity was purely routine, mechanistic, and procedural, and she displayed a very low level of cognitive engagement. She only

had a single focus--to keep time. Bess was more observant. As the temperature increased, she noted bubbles forming, getting bigger, and starting to rise to the surface of the water. Her primary concerns were keeping track of when and how much ice had melted, and noting changes in bubble formation during the heating process. Most of her comments could at best be described as "observational" which referred to physical phenomena that she noticed. Mary was very observant, used trends in temperature changes to predict subsequent temperatures, noted the appearance of bubbles, the formation of steam, and increased evaporation of water at the boiling point. She showed a more sophisticated level of observation which included not only gross, macroscopic features (such as bubbles and steam), but also inferred patterns and trends (e.g., temperature differences). She often thought ahead and anticipated possible outcomes such as the temperature at which water would boil and the effect of salt on the heating of water. She also attempted to explain why the temperature of water remained constant at the boiling point, and why salt water would boil at a higher temperature than plain water, although her reasons were not completely normative. Nevertheless, it was her ability to concentrate on multiple aspects of the phenomenon and her spontaneous on-line theorizing that made her different from the other two girls. Her comments were not only pitched at the observational level but went beyond this to include those targeted at the conceptual and analytical levels. These conceptual / analytical comments were attempts to integrate current information with prior knowledge, or speculations and explanations as to why an event might occur.

Discussion, Implications, and Conclusions

In this study, meaningful perspectives (with respect to generative thinking, nature of explanations, asking questions, metacognitive activity, and approach to tasks) were developed as part of a framework to describe the characteristics associated with a deep and a surface approach to learning science and to compare the differences between them. In summary, when students used a deep approach, they generated their ideas more spontaneously and their responses were more precise and elaborate. They also gave microscopic theory-like explanations which described non-observable entities and cause-effect relationships. Explanations associated with a surface learning approach tended to be reformulations of the question, a "black box" variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible. Questions associated with a deep approach focused on explanations and causes, predictions, or resolving discrepancies in knowledge, and had a greater potential to lead to an advancement in conceptual understanding. Questions associated with a surface approach referred to more basic factual or procedural information. When students used a deep approach, they engaged in an active dialogue with themselves, and also displayed more cognitive appraisal and regulatory control of the learning process through ongoing reflective thinking. In their approach to tasks, they tended to think ahead and predict outcomes, showed a more sophisticated level of observation, and were more likely to engage in talk at a higher cognitive level beyond the procedural and observational levels that learners using a surface approach typically engaged in. To facilitate the generation of ideas and expand on their thinking, the students using a deep approach used strategies such as generating mental images, creating analogies, hypothesizing, constructing thought experiments and predicting possible outcomes, giving self-explanations and

constructing theories, invoking personal experiences and prior knowledge and applying them to new situations, thinking of specific examples, and asking questions.

In this study, the nature of the students' learning approach was studied at a "fine grain" level involving analysis of their thinking processes, cognitive and metacognitive strategies. While Marton's (1983) conceptualization of the deep and surface approaches was used as an overarching framework, the identification of finer differences between these approaches has provided a more elaborate description and complete picture of what is meant by deep and surface learning approaches in the context of science learning. This goes beyond earlier descriptions which were more general, broadly defined, less domain-specific, and more pertinent to reading of texts. Moreover, it takes into account those learning strategies that are used when students are engaged in hands-on investigations which are an integral part of learning in science. In this capacity, it has expanded on the previous framework for reading text to include hands-on activities, problem solving and reasoning. The importance of this study also lies in the creation of a terminology that makes it possible to describe and discuss in an explicit and specific way, the differences between a deep and surface learning approach.

One finding that emerged from this study was the recognition of a variety of types of explanation (reformulations of the question, black box, macroscopic, and microscopic) that students typically give, depending on their learning approach. This should be of value to teachers in helping them to recognize the type and quality of explanations that their students give in relation to their learning approaches, as well as the attributes of effective and not so effective explanations. Another contribution of this study pertains to student questioning. A taxonomy of question types which classifies students' questions according to different conceptual levels was developed. Such a classification could be useful in helping teachers to plan their activities so as to foster student questioning at a higher cognitive level that is characteristic of a deep approach.

This study has expanded the knowledge base about students' learning by including more ecologically valid data. The data were derived not only from interviews with students and written tasks, but also from the students' engagement with actual hands-on activities which were carried out during regular science classes. As such, they were situated in the authentic context of a naturalistic setting (Brown, Collins, & Duguid, 1989; Hennessey, 1993), as opposed to a setting outside the classroom context. That is, students' use of strategies was analyzed while the students were actually performing the science tasks. This differs from earlier research which typically used students' self-reports from interviews and questionnaires to obtain information about their approach to learning. This procedure has yielded insights which might not have been obtained from the use of self-report data alone. Furthermore, unlike most previous research on students' learning approaches where the student typically interacted only with the researcher in a one-to-one individual interview (e.g., Dall'Alba, 1986), data from this study also pertained to science activities where the students interacted with their peers in a group setting. This allowed direct comparisons to be made of the students and their learning approaches. A combination of detailed observation, video-recording of hands-on activities,

interviews and written tasks also complemented each other in providing a more holistic picture of the students' learning approaches.

In looking closely at individual students, it was evident that even among the students who used a deep approach, they showed a tendency to be deep in different ways. For example, Rick tended to think of specific hypothetical examples while Mary was more inclined to draw on personal past experience. This can be seen, for example, in their explanations pertaining to the chromatography of pen ink and the effect of salt on the boiling point of water. What this suggests is that students may be more prone to deeper thinking in some dimensions and contexts than in others. By being aware of the multidimensionality of this, teachers could help students deepen their thinking starting from contexts and dimensions where they already show some depth.

Another noteworthy point about the students who used more of a deep approach was that although they were naturally more inclined than the other students to use deep processing strategies (e.g., predicting, self-explaining), this use was not always spontaneous but was manifested only upon further probing or prompting during the interviews and when the students were specifically asked to explain a phenomenon. For example, during the activity on chromatography of pen inks, both Rick and Mary did not think much about the meaning of the R_f as their teacher had not emphasized this. Instead, they were more concerned with the procedure involved in determining the R_f value and getting this task done. However, when they were probed during the interview, they were stimulated to use deeper strategies to extend their thinking about the R_f and were able to generate plausible ideas about the significance of this value. This suggests that these deep thinking processes are sometimes latent in students and surface only under optimal conditions as a result of the interaction between the students' pre-existing cognitive tendency and situational circumstances. Also, in students using more of a deep approach, the deep processing strategies seem to surface more readily while in those using more of a surface approach, the deep strategies seem more deeply embedded. Thus, if left to their own devices, many students may not use deep processing strategies most of the time. Furthermore, not all students are able to develop deep processing strategies on their own. If deep strategies are considered desirable in facilitating learning, then all this suggests that it is necessary for the teacher to foster constructive learning activity through some kind of instructional intervention rather than leaving things to chance. Instructional measures aimed at stimulating deep processing strategies might encourage surface approach learners to change their learning habits and support deep approach students in theirs.

How can a teacher design a learning environment so as to stimulate deep thinking and encourage students to adopt deep processing strategies? Activities which involve questioning, explaining, and predicting can be used to bolster a discussion. But rather than hope that these would just occur spontaneously in students, the teacher can provide a structure to scaffold student discourse by explicitly requiring the students to do these. For example, the teacher can ask students to write their predictions and formulate questions before performing the activity to help them direct their own inquiry and use these questions as a springboard for investigation and discussion. The students can also think about particular questions as they work on

their tasks. Then at the end of the activity, the students can write questions reflecting what they wondered about, what had puzzled them, or what they needed to know to obtain a fuller understanding of the material they have just studied.

To encourage higher levels of constructive activity and foster deep processing strategies in students, the teacher can also ask students to explain how and why certain phenomena occur and to provide explanations to their own questions. When students attempt to account for observed phenomena, they would generate mini-theories. Over time and with continual practice, this on-line theorizing may become more of a habit and thus occur more spontaneously in students. The provision of self-explanations is a constructive activity and in line with the current constructivist zeitgeist. Furthermore, it is also consonant with the current trend in science education toward talking, reflecting, and explaining as ways to learn. The idea of the "talking science approach" (Hawkins & Pea, 1987; Lemke, 1990), that students should talk science rather than just hear science also suggests that student-generated explanations would be an essential component of student discourse. Students can also be told about what counts as an explanation, the attributes of a "good explanation", and be encouraged to move to a "deeper" level of explanation. To encourage students to generate their own questions and explanations and guide stimulation of deeper processing strategies which students may not activate on their own, the teacher can provide self-monitoring and reflection prompts. Such prompts can provide conceptual guidance and the impetus for explanation, and encourage reflection at a level that students do not generally consider. They could also elicit elaboration of students' ideas and encourage integration (Davis, 1996). While some students may not naturally engage in deep processing strategies on their own, the instructional scaffolding strategies and task prompts could serve a cueing purpose to enhance the students' cognitive and metacognitive capabilities that would hopefully lead to the behaviors associated with a deep learning approach.

References

Baird, J. R., Fensham, P. J., Gunstone, R. F., & White, R. T. (1991). The importance of reflection in improving science teaching and learning. Journal of Research in Science Teaching, 28(2), 163-182.

Baird, J. R. & White, R. T. (1982). A case study of learning styles in biology. European Journal of Science Education, 4(3), 325-337.

Biggs, J. (1987). Student approaches to learning and studying. Melbourne: Australian Council for Educational Research.

BouJaoude, S. B. (1992). The relationship between students' learning strategies and the change in their misunderstandings during a high school chemistry course. Journal of Research in Science Teaching, 29(7), 689-699.

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), Advances in instructional psychology (Vol. 1, pp. 77-157). Hillsdale, NJ: Lawrence Erlbaum.

Brown, J. S., Collins, A. & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-42.

Cavallo, A. M. N. & Schafer, L. E. (1994). Relationships between students' meaningful learning orientation and their understanding of genetics topics. Journal of Research in Science Teaching, 31(4), 393-418.

Dall'Alba, G. (1986). Learning strategies and the learner's approach to a problem solving task. Research in Science Education, 16, 11-20.

Davis, E. (1996, April). Metacognitive scaffolding to foster scientific explanations. Paper presented at the meeting of the American Educational Research Association, New York. (ERIC Documentation Reproduction Service No. ED 394 853).

Entwistle, N. J. & Ramsden, P. (1983). Understanding Student Learning. London: Croom Helm.

Hawkins, J. & Pea, R. D. (1987). Tools for bridging the culture of everyday and scientific thinking. Journal of Research in Science Teaching, 24(3), 291-307.

Hegarty-Hazel, E. & Prosser, M. (1991a). Relationship between students' conceptual knowledge and study strategies--part 1:Student learning in physics. International Journal of Science Education, 13(3), 303-312.

Hegarty-Hazel, E. & Prosser, M. (1991b). Relationship between students' conceptual knowledge and study strategies--part 2: student learning in biology. International Journal of Science Education, 13(4), 421-429.

Hennessey, S. (1993). Situated cognition and cognitive apprenticeship: Implications for classroom learning. Studies in Science Education, 22, 1-41.

Lemke, J. L. (1990). Talking science: Language, learning, and values. Norwood, NJ: Ablex.

Lincoln, Y. S. & Guba, E. G. (1985). Naturalistic inquiry. Newbury Park, CA: Sage.

Marton, F. (1983). Beyond individual differences. Educational Psychology, 3, 289-303.

Marton, F. & Saljo, R. (1976). On qualitative differences in learning. I - Outcome and process. British Journal of Educational Psychology, 46, 4-11.

Rath, A. & Brown, D. E. (1996). Modes of engagement in science inquiry: A microanalysis of elementary students' orientations toward phenomena at a science summer camp. Journal of Research in Science Teaching, 33(10), 1083-1097.